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AN INTEGRATED APPROACH TO REDUCED SIGNATURE TARGET RECOGNITION

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The scientific results provided significant unification of theories from computer vision and statisitical pattern recognition with physics-based models of ATR sensors, as well as extensions of mathematical signal processing techniques such as multiresolution representations to ATR relevant domains. The research has laid the foundation for many years of exploration of new approaches to ATR in reduced signature environments. The research has also developed important technologies to address future hard ATR problems that are of critical DOD interest. These problems include detection of buried objects such as plastic mines, or bunkers, classification of targets in difficult environments such as under tree, recognition of highly variable targets in complex environments, and integration of information from multiple sensors. These techniques are ideal for future DOD and Air Force capabilities based on the profliferation of sensors in order to achieve information dominance.

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REDUCED SIGNATURE TARGET RECOGNITION
MURI 1995

MURI - AFOSR Grant No. F49620-96-1-0028

GRANT TITLE: "An Integrated Approach to Reduced Signature Target Recognition"

PRINCIPAL INVESTIGATOR: Professor David A. Castañón

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PROGRAM OBJECTIVE:

The scope of this program is to conduct basic research in an integrated, multidisciplinary program in automated target recognition (ATR), focusing on the problems created by reduced signature targets. These problems include highly variable targets with low signal level signatures embedded in noisy, cluttered environments, targets obscured by foliage, or buried underground, or partially buried with distorted signatures, new classes of targets which are outside the known training set of targets. The primary objective of the research is furthering the development of a fundamental theory of reduced signature target recognition that can be used as the basis for future ATR systems. Of equal importance are the academic objectives of developing researchers trained in multidisciplinary approaches to ATR, and disseminating knowledge of the ATR research domain throughout the academic community. A final objective is to generate techniques which can be transitioned to industry and government laboratories in order to address important new problems in ATR.

MURI CONSORTIUM RESEARCH TEAM MEMBERS:

- **BOSTON UNIVERSITY: Electrical Engineering:** Profs. David Castañón (PI), Prof. W. Clem Karl; **Computer Engineering:** Prof. Richard Brower; **Aerospace and Mechanical Engineering:** Prof. Leo Felsen
- **NORTHEASTERN University: Electrical and Computer Engineering:** Prof. Eric Miller, Prof. Anthony Devaney
- **NYU: Mathematics.:** Prof. Stephane Mallat; **Computer Science:** Prof. Davi Geiger
- **STANFORD:** Statistics: Prof. David L. Donoho
- **MIT: Electrical Engineering:** Prof. Alan Willsky, Prof. Jeffrey Shapiro; **Computer Science:** Prof. W. Eric L. Grimson, Prof. Paul Viola; **Mathematics:** Prof. Gilbert Strang
- **MICHIGAN:** Electrical Engineering: Prof. Alfred Hero, Prof. Demosthenis Teneketzis;
- **MINNESOTA:** Electrical Engineering: Prof. Ahmed Tewfik, Prof. Allen Tannenbaum

SCIENTIFIC APPROACH: (Indicate how the MURI team collaborated in multidisciplinary research)

The scientific approach was based on the development of new statistical modeling formalisms, which integrate the important considerations in ATR, along with the specification of associated algorithmic theories which perform the critical functions of RSTR. Of particular importance was to explore techniques which integrate information from multiple sources, including prior information concerning likely object characteristics. The research was organized into four major problem areas: Target/Sensor Modeling, Image Processing and Feature Extraction, Image Understanding/Object Recognition and Decision-Directed Sensor and Algorithm Management. The first area, Target/Sensor Modeling, involved collaborations among researchers at BU, MIT and Northeastern on synthetic aperture radar (SAR) modeling, ground-penetrating radar and laser radar (LADAR) modeling. The second area, Image Processing and Feature Extraction, involved collaborations among all seven academic partners to develop new concepts for image representation, nonlinear statistical processing, multiresolution image enhancement, information fusion and geometric feature extraction. The third area, Image Understanding/Object Recognition, involved collaborations among BU, Michigan, MIT and NYU to develop recognition algorithms for reduced signature targets in articulated, partially obscured and highly variable environments. The final area, Decision-Directed Sensor and Algorithm Management, involved researchers from BU, MIT, Minnesota and Michigan to develop new concepts for sensor management and adaptive algorithm processing for improving target recognition.

ACCOMPLISHMENTS:

The major multidisciplinary results of the research can be summarized along eight thrusts. The thrusts and some of the principal accomplishments under each thrust are listed below, along with the collaborating universities:

1) Multiresolution statistical image processing and understanding
- New multiresolution SAR processing for recognition of anisotropic scatterers. (MIT)
- New theories for sparse multiresolution representation of 2-dimensional and 3-dimensional data, extending the concepts of wavelets. This resulted in the invention of ridgelets, beamlets and curvelets. (Stanford, BU, MIT)

- · Statistical algorithms based on wavelet packet representations for deblurring noisy images, which have been adapted for high resolution focusing of satellite imagery. (Stanford, NYU)
- New LADAR processing techniques, combining physics models, multiresolution stochastic models, fast estimation algorithms, and advanced maximum likelihood hypothesis testing. (MIT, BU)

2) Geometric deformable contour approaches for low SNR image reconstruction
- Differential geometry techniques using curve evolution for segmentation of general 2-D and 3-D shapes. (Minnesota, MIT)
- Extension to rapid segmentation of objects based on region rather than local information with application to SAR and LADAR segmentation (MIT, BU, Northeastern)
- Extension to the solution of ill-posed linear and nonlinear inverse problems in applications such as ground penetrating radar, diffraction tomography and SAR image formation. (BU, Northeastern)

3) Complex object recognition
- A new theory for robust detection of objects in unknown, complex clutter based on maximally invariant statistics, leading to new classes of constant false alarm rate (CFAR) algorithms. (Michigan)
- Fast computational algorithms for solution of optimization problems in maximum likelihood estimation for detection of weak targets. (Michigan, BU)
- Variational approaches for recognition of articulated objects based on matching deformations of their skeletons, combining concepts from optimization and computer science. (NYU)
- A complete statistical theory for recognition of partially obscured objects. (BU, MIT)

4) Variational image formation
- A variational theory for feature enhanced image formation using SAR. (BU,MIT)
- Extensions of variational theories to construct SAR images of moving objects with unknown velocities. (MIT)
- A graph theoretic approach for solution of variational problems. (NYU)

5) Learning and ATR
- An estimation-theoretic approach to building 3-D electromagnetic CAD models based on multiple collections of SAR imagery. (MIT)
- Statistical approaches which integrate learning together with differential geometry segmentation and obscured object recognition techniques. (BU, MIT)
- Learning theory approaches for efficient image compression for recognition. (MIT)

6) Multisensor Fusion
- A theory of multimodal image registration based on intensity values instead of extracted features, using the concept of maximal mutual information registration. (MIT)
- Robust extension of mutual information image registration to imagery extracted using bright points, applied to registration of SAR imagery. (Michigan)
- Mutual information registration of dynamic imagery using multimodal information. (MIT)
- Differential geometry registration using mass preserving diffeomorphisms with minimal deformation (Minnesota).

7) Imaging in complex environments
- Algorithms for nonlinear diffraction tomography, leading to accurate imaging in scattering media, with applications to underground imaging using ground penetrating radar, and ultrasound imaging. (Northeastern)
- Gaussian beam expansions for electromagnetic and acoustic inverse scattering problems through unknown media, leading to efficient physical models for representation of subsurface target/sensor interactions. (BU)
- Adaptive inversion techniques for imaging through unknown rough interfaces using time-domain broad bandwidth excitation. (BU)
- Computational time reversal algorithms for multistatic detection of targets under unknown cover such as foliage or subsurface imagery. (Northeastern)

8) Sensor and algorithm management
- New algorithms for sensor management. (BU, Minnesota)
- Multiscale algorithms for hypothesis search in ATR (BU, Northeastern)
- Multisensor target search scheduling algorithms, applied to SAR target search (BU,Michigan).

PUBLICATIONS (awards, papers, invitations, and patents):

The work in this MURI has led to over 400 refereed publications, including over 200 refereed journal and book chapter publications. In addition, there were three patents and two invention disclosures which resulted from the research efforts. Below is a partial list of honors and awards received by the MURI participants:

- MURI participants deliverd 19 plenary lectures at major international meetings (IEEE, AMS, SIAM).
- Prof. Willsky was named a member of the Air Force's Scientific Advisory Board in 1998.

- Prof. Castañon was program chair of the 1998 Conference on Decision and Control, and served on the IEEE Control System Society's Board of Governors from 1998-2000.
- Prof. Strang served as President of SIAM during 1999-2000 and was Chair of the Joint Policy Board for Mathematics. He chaired SIAM's Committee on Science Policy in 2001.
- Prof. Tannenbaum won the Best Paper Award, Society of Plastic Engineers in 2001.
- Prof. Donoho was named P.R. Krishnaiah Memorial Lecturer, Penn. State University, May 2000, was elected a member of the National Academy of Sciences in 1998, and received an Outstanding Achievement award from SPIE in 2000. He was awarded SIAM's von Neumann Prize and delivered the von Neumann lecture at SIAM Annual Meeting in 2001, and was selected a Phi Beta Kappa National Lecturer in 2002-2003.
- Graduate student Emmanuel Candes was awarded the Popov Prize in Approximation Theory.
- Prof. Tewfik received the IEEE Third Millennium Award, 2000 and was named Distinguished Lecturer of the IEEE, Signal Processing Society, 1997.

IMPACT (a. technology/science areas, and b. DOD/AF capability):

The scientific results provided significant unification of theories from computer vision and statistical pattern recognition with physics-based models of ATR sensors, as well as extensions of mathematical signal processing techniques such as multiresolution representations to ATR relevant domains. The research has laid the foundation for many years of exploration of new approaches to ATR in reduced signature environments. The research has also developed important technologies to address future hard ATR problems that are of critical DOD interest. These problems include detection of buried objects such as plastic mines or bunkers, classification of targets in difficult environments such as under tree, recognition of highly variable targets in complex environments, and integration of information from multiple sensors. These techniques are ideal for future DOD and Air Force capabilities based on the proliferation of sensors in order to achieve information dominance.

TECHNOLOGY TRANSITION/TRANSFER :

The MURI research was transitioned to a number of different DOD programs, as well as to other non-military programs. A partial list of technology transitions is included below:
- **AFRL – Dayton:** FOPEN SAR and hyperspectral image fusion, robust image segmentation for SAR/FLIR fusion, statiscal SAR segmentation, rapid target segmentation using active contours, multiresolution feature-aided tracking
- **AFRL – Eglin:** LADAR image formation and segmentation is aimed at transitioning into programs for ATR using LADAR in autonomous munitions concepts such as LOCASS.
- **Lincoln Laboratory:** multiresolution feature extraction for aspect-dependent SAR was transitioned to SAR ATR programs, with a focus for insertion of the technology into the SAIP system.
- **Draper Laboratory**-stochastic image segmentation using multiresolution models was transitioned to Draper, for segmentation in biomedical images.
- **Textron** – multiresolution stochastic models for feature extraction, recognition in complex, variable environments for FLIR ATR with pose uncertainty in DAMOCLES program.
- **Lockheed Martin** is evaluating the new multiresolution representations using curvelets, beamlets and ridgelets for data compression and improved signal denoising in ATR applications.
- **ERIM/Veridian** - robust mutual information registration for SAR imagery and multispectral visual imagery. Robust detection and processor scheduling was also transitioned to similar SAR programs.
- **Brigham and Women's and Massachusetts General Hospitals:** Curve evolution for image segmentation, variational inverse problems, edge-preserving smoothing and multi-modality image registration for image guided surgery.
- **ALPHATECH – DARPA:** DARPA ATR technology demonstration programs in collaboration with ALPHATECH: MSTAR, SEP Global Hawk Program, Discoverer II, and the DDB program. Specific technology: road segmentation in SAR imagery, sensor management, hypothesis search, multiresolution statistical image processing, information-theoretic multisensor registration, 3-D SAR model construction, and FOPEN SAR recognition. Multiresolution fusion has also transitioned into NIMA programs for fusion of terrain elevation data taken at different resolutions. The results on ATR and learning are being applied to the problem of HRR (high-range resolution radar) feature-aided tracking (FAT).
- **NIH** – The results on curve evolution were transitioned to brain image segmentation for the temporal tracking of multiple sclerosis lesions and for MRI segmentation of the prostate for in order to guide cancer treatment.
- **French Spatial Agency** – is using the wavelet packet deblurring algorithms for remote sensing.

EDUCATION/TRAINING (Students benefit from the program):

The MURI effort included participation by 68 students. Over the duration of the MURI, these students completed 41 Ph. D. dissertations and 32 M.S. dissertations.